

UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2010/2011 Academic Session

April/May 2011

EKC 216 – Process Heat Transfer
[Pemindahan Haba Proses]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SEVEN printed pages and THREE printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan TIGA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

[Arahan: Jawab **SEMUA** soalan.]

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

1. [a] A wall with a cross sectional area of 2.5 m^2 consists of 12 cm thickness of concrete [$k = 1.2 \text{ W/(m.K)}$], 4.5 cm thickness of fiberglass insulation [$k = 0.038 \text{ W/(m.K)}$], and 0.85 cm thickness of gypsum board [$k = 0.05 \text{ W/(m.K)}$]. The inside and outside convection coefficients are 11.34 and $36.69 \text{ W/(m}^2\text{.K)}$, respectively. The inside air temperature is 25°C , and the outside temperature is -1°C . Calculate the

Satu dinding berkeluasan 2.5 m^2 terdiri daripada konkrit [$k = 1.2 \text{ W/(m.K)}$], berketebalan 12 sm, penibat kaca gentian [$k = 0.038 \text{ W/(m.K)}$] berketebalan 4.5 sm, dan papan gipsum [$k = 0.05 \text{ W/(m.K)}$] berketebalan 0.85 sm. Pekali perolakan bahagian dalam dan luar dinding masing-masing ialah 11.34 dan $36.69 \text{ W/(m}^2\text{.K)}$. Suhu udara pada bahagian dalam ialah 25°C dan pada bahagian luar ialah -1°C . Kirakan

 - [i] overall heat-transfer coefficient for the wall,
pekali pemindahan haba keseluruhan untuk dinding tersebut,
 - [ii] total thermal resistance,
rintangan termal keseluruhan,
 - [iii] the heat loss and
kehilangan haba
 - [iv] temperature at the interface between fiberglass and gypsum board.
suhu pada permukaan antara kaca gentian dan papan gipsum.

[8 marks/markah]
- [b] A certain superinsulation material [$k = 4.2 \times 10^{-4} \text{ W/(m.K)}$] is used to insulate a tank of liquid nitrogen that is maintained at -196°C . 158 kJ is required to vaporize each kilogram mass of nitrogen at this temperature. Assuming that the tank is a sphere having an inner diameter of 0.66 m with an insulation thickness of 2.8 cm and an outer temperature of 20°C , estimate the amount of nitrogen vaporized per day.

Satu bahan penibat lampau [$k = 4.2 \times 10^{-4} \text{ W/(m.K)}$] digunakan untuk menebat tangki nitrogen cecair yang suhunya tetap pada -196°C . 158 kJ diperlukan untuk mengewapkan setiap jisim kilogram nitrogen pada suhu ini. Anggapkan tangki berbentuk sfera dengan diameter dalam 0.66 m dan tebal penibat 2.8 sm dan suhu di bahagian luar 20°C , kirakan jumlah nitrogen meruap per hari.

[3 marks/markah]
- [c] Draw the temperature distributions of pin fin with 16 cm long and 2.2 cm diameter which is exposed to environment [$h = 9.8 \text{ W/(m}^2\text{.K)}$] at 30°C , for two fin materials;

Lukiskan taburan suhu untuk sirip pin yang panjang dan diameternya masing-masing 16 sm dan 2.2 sm, terdedah kepada persekitaran [$h = 9.8 \text{ W/(m}^2\text{.K)}$] pada suhu 30°C untuk dua bahan sirip;

- [i] copper [$k=385 \text{ W/(m.K)}$] and
kuprum [$k=385 \text{ W/(m.K)}$] dan
- [ii] stainless steel [$k=15 \text{ W/(m.K)}$].
keluli tahan karat [$k=15 \text{ W/(m.K)}$].

Note: The base temperature is maintained at 250°C . Assume convecting tip condition.

Nota: Suhu tapak ditetapkan pada 250°C . Anggap keadaan hujung sirip perolakan.

[8 marks/markah]

- [d] A thin rectangular plate of 5 cm length and width of 12 cm is buried in the earth with a depth of 20 cm. The plate temperature is 82°C , and the heat lost by the plate is 13.73W. Calculate the earth surface temperature by assuming the thermal conductivity of the earth is $0.8 \text{ W/(m.}^\circ\text{C)}$.

Satu plat nipis segiempat yang panjang dan lebarnya masing-masing ialah 5 sm dan 12 sm ditanam di dalam bumi pada kedalaman 20 sm. Suhu plat ialah 82°C dan haba hilang pada plat ialah 13.73W. Kirakan suhu permukaan bumi dengan mengangap konduktiviti termal bumi ialah $0.8 \text{ W/(m.}^\circ\text{C)}$.

[3 marks/markah]

- [e] An aluminum ball of 60 cm in diameter with uniform temperature of 700°C is suddenly immersed in a fluid at 30°C . If the convection coefficient is estimated at $120 \text{ W/(m}^2\text{.K)}$, how long will it take for the ball to cool to 100°C ? Given: k , ρ , and c for the aluminum as 190 W/(m.K) , 2500 kg/m^3 and 0.896 kJ/(kg.K) , respectively.

Satu bola aluminium berdiameter 60 sm dan bersuhu seragam 700°C direndam secara mengejut di dalam bendalir bersuhu 30°C . Jika pekali perolakan ialah $120 \text{ W/(m}^2\text{.K)}$, berapakah masa yang diperlukan oleh bola tersebut untuk mencapai suhu 100°C ? Diberi k , ρ dan c untuk aluminium masing-masing sebagai 190 W/(m.K) , 2500 kg/m^3 dan 0.896 kJ/(kg.K) .

[3 marks/markah]

2. [a] Air at 77°C , 2 atm and velocity of 15 m/s is heated as it flows through a tube with a diameter of 40 mm. Calculate the heat transfer for 5 m length of tube if a constant-heat-flux condition is maintained. All along the length of the tube, the wall temperature is 25°C above the air temperature.

Udara pada 77°C , 2 atm dan berkelajuan 15 m/s dipanaskan apabila melalui tiub yang mempunyai diameter dan panjang masing-masing ialah 40 mm dan 5 m. Kirakan pemindahan haba sekiranya keadaan fluks-haba-tetap ditetapkan. Untuk sepanjang tiub ini, suhu dindingnya ialah 25°C melebihi suhu udara.

[5 marks/markah]

- [b] Air at 1 atm and 25°C flows across a bank of tubes 10 rows high and 10 rows deep at a velocity of 12 m/s measured at a point in the flow before the air enters the tube bank. The surfaces of the tubes are maintained at 129°C. The diameter of the tube is 2.54 cm with 4 m length. The tubes are arranged in a staggered tube manner so that the spacing in both the normal and parallel direction to the flow is 3.81 cm. Calculate the total heat transfer for the tube bank.

Udara kemasukan pada kelajuan 12 m/s, 1 atm dan 25°C melintasi bank tiub yang terdiri daripada 10 baris tinggi dan 10 baris ke dalam. Suhu permukaan tiub tetap pada 129°C. Diameter dan panjang tiub masing-masing ialah 2.54 sm dan 4 m. Tiub-tiub disusun secara susunan tak serentak yang mana jarak normal dan selari pada arah aliran ialah 3.81 sm. Kirakan pemindahan haba keseluruhan untuk bank tiub.

[12 marks/markah]

- [c] Calculate the free-convection heat loss from a 0.36 m² vertical square plate maintained at 229°C and exposed to air at 25°C and 1 atm.

Kirakan haba hilang secara perolakan bebas oleh plat menegak segiempat sama bersuhu tetap 229°C dan terdedah kepada udara bersuhu 25°C dan 1 atm.

[4 marks/markah]

- [d] A horizontal fine wire having a diameter of 0.1 mm and length of 5 m is maintained at a temperature of 124°C by an electric current. The wire is exposed to air at 1 atm and 30°C. Calculate the electric power necessary to maintain the wire temperature.

Satu wayar halus mendatar mempunyai diameter dan panjang masing-masing ialah 0.1 mm dan 5 m serta bersuhu tetap pada 124°C oleh arus elektrik. Wayar ini terdedah kepada udara pada 1 atm dan 30°C. Kirakan kuasa elektrik yang diperlukan untuk mengekalkan suhu wayar tersebut.

[4 marks/markah]

3. [a] A 5m square room has a ceiling and a floor maintained at 28°C and 20°C respectively. The connecting walls are 4m high and perfectly insulated. Emissivity of the ceiling is 0.62 and that of the floor is 0.75. Calculate

Suatu bilik bersegiempat sama 5m mempunyai siling bersuhu 28°C dan lantai bersuhu 20°C kekal pada suhu yang sama. Dinding yang bersambung mempunyai ketinggian 4m dan ditebat sepenuhnya. Keber Pancaran siling ialah 0.62 dan 0.75 untuk lantai. Kirakan

- [i] the heat transfer from ceiling to floor (W).
pemindahan haba dari siling ke lantai (W).

[5 marks/markah]

- [ii] the temperature of the connecting walls (°C).
suhu dinding yang bersambungan (°C).

[3 marks/markah]

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- [b] A furnace in the form of a cylinder of 75mm diameter and 150mm length is open at one end to large surroundings at 27°C. The side and bottom are heated electrically at 1350°C and 1650°C respectively. Calculate the power to maintain the furnace condition.

Suatu relau berbentuk silinder yang mempunyai garispusat 75mm dan panjang 150mm terdedah salah satu sisinya kepada persekitaran yang luas pada 27°C. Bahagian sisi dan bawahnya masing-masing dipanaskan secara elektrik pada 1350°C dan 1650°C. Kirakan kuasa bagi mengekalkan keadaan relau itu.

[6 marks/markah]

- [c] Three infinite parallel plates are placed in a space. Plate 1 and 3 are maintained at 1200K and at 300K respectively. The emissivity of each plate is: $\epsilon_1=0.2$, $\epsilon_2=0.5$, $\epsilon_3=0.8$. Assuming that there is no external heat other than from plate 1 and 3, calculate the temperature of plate 2 (K).

Tiga plat yang berselari tanpa batasan diletakkan di suatu ruang. Plat 1 dikekalkan pada 1200K dan plat 3 pada 300K. Keberpancaraan setiap plat ialah: $\epsilon_1=0.2$, $\epsilon_2=0.5$, $\epsilon_3=0.8$. Andaikan tiada haba luaran selain daripada plat 1 dan 3, kirakan suhu plat 2 (K).

[6 marks/markah]

- [d] A white marble slab ($\alpha_{\text{sun}}=0.46$, $\alpha_{\text{low}}=0.95$) is exposed to a solar radiation flux of 1070W/m². Assuming the effective radiation temperature of the sky is -70°C, calculate the radiation equilibrium temperature of the slab.

Suatu kepingan marmar putih ($\alpha_{\text{matahari}}=0.46$, $\alpha_{\text{rendah}}=0.95$) didedahkan kepada fluks radiasi suria 1070W/m². Andaikan suhu radiasi efektif langit ialah -70°C, kirakan suhu keseimbangan radiasi bagi kepingan tersebut (°C).

[5 marks/markah]

4. [a] A shell and tube heat exchanger is to be designed to heat 7.5kg/s of water from 85 to 99°C. The heating is accomplished by condensing steam at 345 kPa. One shell pass is used along with two tube passes, each consisting of thirty smaller 2.5cm OD tubes. Assuming a U of 2800 W/(m².°C), calculate the length of tubes (in meter) required in the heat exchanger.

Suatu penukar haba tiub kelompang direkabentuk untuk memanaskan 7.5kg/s air daripada 85 ke 99°C. Pemanasan dibuat dengan cara menkondensasikan stim pada 345 kPa. Satu laluan kelompang digunakan bersama-sama dengan dua laluan tiub, salah satu mempunyai tiga puluh tiub lebih kecil bergarispusat 2.5sm. Andaikan nilai U ialah 2800 W/(m².°C), kirakan panjang tiub (dalam meter) yang diperlukan untuk penukar haba tersebut.

Given:

Diberi:

$$\rho_l=1118.281 \text{ kg/m}^3, \rho_g=1.715 \text{ kg/m}^3, \mu=1.72 \times 10^{-4} \text{ kg/(m.s)}, h_{fg}=343 \text{ kJ/kg}$$

$$c_{p,l}=4175 \text{ kJ/(kg.°C)}, T_{\text{sat}}=138^\circ\text{C}, k_l=0.1894 \text{ W/(m.K)}$$

[4 marks/markah]

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- [b] Condensing carbon dioxide at 20°C is in contact with a horizontal 10 cm diameter tube maintained at 15°C. Calculate the condensation rate per meter length (in kg/hr).

Karbon dioksida terkondensasi pada 20 °C bersentuhan dengan tiub melintang bergaris pusat 10 sm yang dikekalkan pada 15 °C. Kirakan kadar kondensasi per meter panjang (dalam kg/jam).

Given:

Diberi:

$$T_f = 17.5^\circ\text{C}, \rho = 795\text{ kg/m}^3, h_{fg} = 153.2\text{ kJ/kg}, \mu = 6.87 \times 10^{-5}\text{ Ns/m}^2,$$

$$c_{p,l} = 4214\text{ J/(kg.K)}, k = 0.0897\text{ W/(m.K)}, Pr = 3.78$$

[6 marks/markah]

- [c] A 500g of water is placed inside a water bath at 100°C. The bottom of the water bath is a metal clad heating element of 0.3m diameter and emissivity, $\varepsilon=1$. If the surface temperature of the metal is then raised and maintained at 155°C, how long will it take for the water to vaporize completely from the bath (in hours)?

Air sebanyak 500g diletakkan di dalam suatu mandian air pada 100 °C. Di bahagian bawah mandian ialah logam pemanas bergaris pusat 0.3 m dan keberpancaran, $\varepsilon=1$. Sekiranya suhu permukaan logam dinaikkan dan dikekalkan pada 155°C, berapa lamakah masa yang diperlukan untuk mengewap keseluruhan air tersebut (dalam jam)?

Given:

Diberi:

$$\rho_l = 957.9\text{ kg/m}^3, h_{fg} = 2257\text{ kJ/kg}, \rho_v = 4.808\text{ kg/m}^3,$$

$$c_{p,v} = 2.56\text{ kJ/(kg.K)}, k_v = 0.0331\text{ W/(m.K)}, \mu_v = 14.85 \times 10^{-6}\text{ N.s/m}^2,$$

$$C = 0.62, \sigma = 5.669 \times 10^{-8}\text{ W/(m}^2\text{K}^4)$$

[6 marks/markah]

- [d] A vertical plate at 91°C is exposed to saturated steam at 1 atm. Determine:
Satu plat menegak pada 91°C didedahkan kepada stim tepu pada 1 atm. Tentukan:

- [i] the height of plate (in meter) to just produce a Reynolds number of 1800.

ketinggian plat (dalam meter) untuk mencapai nombor Reynolds 1800.

[5 marks/markah]

- [ii] the rate of condensation [in kg/(s.m)].
kadar kondensasi [dalam kg/(s.m)].

[4 marks/markah]

Given:

$$\rho_l = 961 \text{ kg/m}^3, h_{fg} = 2255 \text{ kJ/kg}, \rho_v = 4.808 \text{ kg/m}^3, c_{p,v} = 2.56 \text{ kJ/(kg.K)},$$
$$k_v = 0.68 \text{ W/(m.K)}, \mu_v = 2.97 \times 10^{-4} \text{ N.s/m}^2, C = 1.13,$$
$$\sigma = 5.669 \times 10^{-8} \text{ W/(m}^2\text{K}^4)$$

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Appendix

For spherical shell; $q = \frac{T_i - T_o}{\frac{1}{(4\pi k) \left(\frac{1}{r_i} - \frac{1}{r_o} \right)}}$

For lumped parameter analysis; $Bi = \frac{hL_c}{k}$; $\tau_c = \frac{C\rho L_c}{h}$; $\frac{T - T_\infty}{T_o - T_\infty} = e^{-\tau/\tau_c}$

For laminar flow in pipe; $Nu_d = 3.66 + \frac{0.0668 \left(\frac{d}{L} \right) Re_d Pr}{1 + 0.04 \left[\left(\frac{d}{L} \right) Re_d Pr \right]^{2/3}}$

For turbulent flow in pipe: $Nu_d = 0.023 Re_d^{0.8} Pr^{0.4}$

For tube bank; $Nu = C(Re)^n Pr^{1/3}$

For in-line tube manner; $u_{\max} = u_\infty [S_n / (S_n - d)]$

For staggered tube manner; $u_{\max} = \frac{u_\infty (S_n / 2)}{\left[(S_n / 2)^2 + S_p^2 \right]^{1/2} - d}$

$q = hA(T_w - \frac{T_{\infty 1} + T_{\infty 2}}{2}) = m_{\infty 1} c_p (T_{\infty 2} - T_{\infty 1})$

For free convection; $Gr Pr = \left(\frac{g\beta(T_w - T_\infty)x^3}{\nu^2} \right) Pr$; $Nu = C(Gr Pr)^m$

$\bar{h}_L = 0.943 \left[\frac{g\rho_l(\rho_l - \rho_v)k_l^3 h'_{fg}}{\mu_l(\Delta T)L} \right]^{1/4}$, $q = \bar{h}_L A(\Delta T)$, $Re_\delta = \frac{4\dot{m}}{\mu_l b}$, $\dot{m} = \frac{\bar{h}A(T_g - T_w)}{h_{fg}}$

$q' = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma'} \right]^{1/2} \left(\frac{c_{p,l} \Delta T_x}{C_{sf} h_{fg} Pr_l^s} \right)^3$, $\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = 1.47 Re^{-1/3}$

$h^{4/3} = h_{conv}^{4/3} + h_{rad} h^{1/3}$, $\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = \frac{Re}{1.08 Re^{1.22} - 5.2}$

$h_{conv} = \frac{Ck_v}{D} \left[\frac{g(\rho_l - \rho_v)h_{fg} D^3}{\nu_v k_v (T_s - T_{sat})} \right]^{1/4}$, $\frac{\bar{h}(v^2/g)^{1/3}}{k_l} = \frac{Re}{8750 + 58 Pr^{-0.5} (Re^{0.75} - 253)}$

$h_{rad} = \frac{\varepsilon \sigma (T_s^4 - T_{sat}^4)}{(T_s - T_{sat})}$, $\bar{h} = 0.725 \left[\frac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{N\mu_l(T_{sat} - T_s)D} \right]^{1/4}$, $\bar{h} = C \left[\frac{\rho_l(\rho_l - \rho_v)gh_{fg}k_l^3}{\mu_l(T_{sat} - T_s)L} \right]^{1/4}$

Tip Condition	Temp. Distribution	Fin heat transfer
Convection heat transfer: $h\theta(L) = -k(d\theta/dx)_{x=L}$	$\frac{\cosh m(L-x) + (h/mk) \sinh m(L-x)}{\cosh mL + (h/mk) \sinh mL}$	$M \frac{\sinh mL + (h/mk) \cosh mL}{\cosh mL + (h/mk) \sinh mL}$
Adiabatic $(d\theta/dx)_{x=L} = 0$	$\frac{\cosh m(L-x)}{\cosh mL}$	$M \tanh mL$

TABLE 1 : Conduction shape factors.

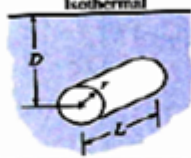

Physical system	Schematic	Shape factor	Restrictions
Isothermal cylinder of radius r buried in semi-infinite medium having isothermal surface		$\frac{2\pi L}{\cosh^{-1}(D/r)}$ $\frac{2\pi L}{\ln(D/r)}$	$L \gg r$ $L \gg r$ $D \gg r$
Thin rectangular plate of length L , buried in semi-infinite medium having isothermal surface		$\frac{\pi W}{\ln(4W/L)}$ $\frac{2\pi W}{\ln(4W/L)}$ $\frac{2\pi W}{\ln(2\pi D/L)}$	$D = 0$ $W > L$ $D \gg W$ $W > L$ $W \gg L$ $D > 2W$

TABLE 2 : Properties of air at atmospheric pressure†

The values of μ , k , c_p , and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures.							
T , K	ρ kg/m ³	c_p , kJ/kg · K	$\mu \times 10^5$, kg/m · s	$\nu \times 10^6$, m ² /s	k , W/m · K	$\alpha \times 10^4$, m ² /s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680

TABLE 3 : Modified correlation of Grimson for heat transfer in tube banks of 10 rows or more

$\frac{S_p}{d}$	$\frac{S_n}{d}$							
	1.25		1.5		2.0		3.0	
	C	n	C	n	C	n	C	n
Staggered								
0.6	—	—	—	—	—	—	0.236	0.636
0.9	—	—	—	—	0.495	0.571	0.445	0.581
1.0	—	—	0.552	0.558	—	—	—	—
1.125	—	—	—	—	0.531	0.565	0.575	0.560
1.25	0.575	0.556	0.561	0.554	0.576	0.556	0.579	0.562
1.5	0.501	0.568	0.511	0.562	0.502	0.568	0.542	0.568
2.0	0.448	0.572	0.462	0.568	0.535	0.556	0.498	0.570
3.0	0.344	0.592	0.395	0.580	0.488	0.562	0.467	0.574

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TABLE 4 : Constant for use with Eq. (7-25) for isothermal surfaces

Geometry	$Gr_f Pr_f$	C	m
Vertical planes and cylinders	$10^{-1}-10^4$	Use Fig. 7-7	Use Fig. 7-7
	10^4-10^9	0.59	$\frac{1}{4}$
	10^9-10^{13}	0.021	$\frac{5}{8}$
	10^9-10^{13}	0.10	$\frac{1}{3}$
Horizontal cylinders	$0-10^{-5}$	0.4	0
	$10^{-5}-10^4$	Use Fig. 7-8	Use Fig. 7-8
	10^4-10^9	0.53	$\frac{1}{4}$
	10^9-10^{12}	0.13	$\frac{1}{3}$
	$10^{-10}-10^{-2}$	0.675	0.058
	$10^{-2}-10^2$	1.02	0.148
	10^2-10^4	0.850	0.188
	10^4-10^7	0.480	$\frac{1}{4}$
	10^7-10^{12}	0.125	$\frac{1}{3}$

TABLE 5 : Radiation shape factor for radiation between parallel rectangles.

